COSMIC-RAY EXPOSURE AGE OF A 480 MYR OLD FOSSIL METEORITE BY NOBLE GAS ANALYSES OF RELICT CHROMITE GRAINS. Ph. R. Heck¹, H. Baur¹, B. Schmitz² and R. Wieler¹, ¹Isotope Geology, NO C61, ETH, CH-8092 Zürich, Switzerland, heck@erdw.ethz.ch, ²Marine Geology, Earth Science Centre, P.O. Box 460, SE-405 30 Göteborg, Sweden, birger@gvc.gu.se.

Abstract: We detected cosmogenic ³He and ²¹Ne in 6 individual chromite grains from a fossil meteorite recovered from a quarry in Lower Ordovician (480 Ma) marine limestone in southern Sweden. Helium and neon exposure ages agree with each other at ~300'000 years, suggesting neglible loss of cosmogenic He and Ne. This exposure age is at the very low end of the range of values observed for present-day meteorites.

Introduction: Schmitz et al. [1] found forty fossil meteorites in the Thorsberg quarry (58°35'N, 13°26'E) at Kinnekulle, southern Sweden. This allowed to estimate that the meteorite flux to Earth 480 Ma ago has been one to two orders of magnitude higher than today. This higher flux was probably generated by the collisional breakup of an L chondrite parent body in the asteroid belt [1].

Our goal is to determine exposure ages of fossil meteorites from different stratigraphic locations to learn more about the breakup event. This study presents results from the first meteorite investigated. Chemical and isotopic analyses [1] indicate that the meteoritic chromite grains were not significantly altered by diagenesis although the other mineral phases were completely altered. The relict mineral grains allowed most of the fossil meteorites to be classified as ordinary chondrites, most probably L chondrites.

Samples and Experimental: To date we have analyzed helium and neon isotopes of six chromite grains from the fossil meteorite Golvsten 001 with a ultra-high-sensitivity noble gas mass spectrometer. The meteorite was found in the red Golvsten bed, overlain by \sim 6-7 m of limestone and Quaternary till. The Golvsten bed is near the lower end of the sedimentary section which spans an interval of \leq 1.75 Myrs.

Chromite grains were extracted by dissolving the meteorite with hydrochloric acid. The grains were washed with ethanol and cleaned for ~1 minute in an ultrasonic bath. Chromites were identified by visual inspection and handpicked. Randomly selected grains checked for elemental composition with SEM/EDAX confirmed the reliability of this method. The grains were weighted with a high precision balance (10-40 μ g, ~10% error) and placed into an Al-sample holder. Noble gases were extracted by melting the grains in ultra-high vacuum using a continuous-wave Nd-YAG infrared laser. The gas was cleaned using several liquid nitrogen cold traps and ZrAl "getters" to remove active gases. In order to measure He and Ne separately with the appropriate mass resolution, Ne was frozen onto a 14 K cryotrap until the He measurement terminated. The heart of the mass spectrometer is a compressor ion-source [2]. A molecular drag pump compresses the gases into the ionization volume. The gain factor (pressure in the ion source/pressure in the flight tube) is ~ 130 for He ~ 200 for Ne. Ions are detected by a channeltron multiplier in ion-counting mode or a Faraday cup (for ⁴He). A small ZrAl getter in the source itself strongly decreases the background caused by H₂, CO₂ and other active gases. The gas amounts were calibrated by measuring three olivine fragments from the pallasite Admire and comparing the data with previous data of Admire olivines. Exposure ages were calculated using elemental production rates by Leya et al. [3] and average chemical composition of the chromites [1]. The obtained exposure ages are nominal values assuming an average sized preatmospheric body and an average shielding depth corresponding to $(^{22}\text{Ne}/^{21}\text{Ne})_{\cos} = 1.11$. The largest fraction of the cosmogenic Ne is produced by spallation reactions on Mg (~41%), followed by Al (~33%) and Cr (\sim 20%). Fe contributes \sim 6%. ²¹Ne production rates from Cr were extrapolated from the respective values from Fe and Ni [3]. Uncertainties of major target element concentrations in single chromites (10-20% for Al and Mg [1]), uncertainties of elemental production rates and analytical uncertainties result in an overall estimated error of exposure ages on the order of mostly 30-40%.

Results: All chromite grains contain excesses of cosmogenic ³He and ²¹Ne. The measured (not blank corrected) 21 Ne/ 20 Ne-ratios (average value = 0.014) for 5 of 6 grains are well above the atmospheric ratio of 0.00296 (Table 1). Cosmogenic nuclides produced during the 480 Myr residence on Earth can be neglected since the meteorite has been buried until a few years ago below ~6-7 m of limestone and Quaternary till. Before that the burial depth was even much larger. This shielding at the present-day altitude near sea-level yield a very conservative estimate that terrestrial cosmogenic nuclide production accounts for less than 10⁻⁵ of the total observed. Average blanks are $(1.3 \pm$ $0.4)_{-10^{-15}}$ cc STP and $(1.2 \pm 0.4)_{-10^{-15}}$ cc STP for ³He and Ne, respectively. Ne blanks are of atmospheric composition.

All 3 He ages (T_{3}) and also all 21 Ne ages (T_{21}) agree with each other within 2 (Table 1 and Figure 1). The average T_{3} is ~25% lower than the average T_{21} , but within analytical and production rate uncertainties both ages agree. In a pilot study 38 Ar concentrations in three grains were measured with a noble gas mass spectrometer equipped with a conventional ion source. T_{38} ages also agree with T_{3} and T_{21} , although the errors are very large since the cosmogenic Ar amounts are near

the detection limit. Nevertheless, the comparable ages calculated from three different nuclides and the similar nominal ages of all grains leads us to conclude that all cosmogenic gases have been quantitatively retained. The exposure ages on the order of ~300 kyr are unusually short, since only few ordinary chondrites have exposure ages <2 Myr and most of them have ages >10 Myr (e.g. [4]). There are two possibilites to explain this: either the samples are fragments of a very large meteoroid were they have been shielded at much larger depth than assumed here or the ages are real and the meteorites where delivered to Earth shortly after the event that released them from the parent body.

Discussion: Further measurements are needed to decide whether the low exposure ages reported here are real. If so, meteorites from younger sediments should display higher exposure ages than those from older layers, since the high inferred flux stongly suggests that most of the fossil meteorites in the sediment were produced in one very large collision [1]. The data obtained so far suggest that such a difference of up to ~1.7 Myr should well be resolvable with our analytical technique.

Dynamical modelling [5, 6] indicates that large, asteroid family-producing collisions inject a sizeable proportion of the fragments "directly" into an orbital resonance in the main asteroid belt from where they will quickly collide with the sun or a planet. Therefore, very large collisions are indeed expected to produce a larger fraction of meteorites with very low exposure ages than "normal" meteorite producing events. Zappalà et al. [6] predict that many family-producing impacts deliver some 10% of the fragments that ultimately end up on Earth within less than a million years. However, even these events of enhanced meteorite flux last between 2 and 30 Myr. Thus, if the low exposure age reported here is true and representative for other fossil meteorites from the Thorsberg quarry, these sediments rather fortuitously would have sampled just the forerunners of the L-chondrite parent body break-up event ~480 Myr ago. It thus remains to be seen whether the young nominal age of the one meteorite studied here is an artifact due to a grossly overestimated production rate.

Conclusions: We have shown that relict chromite grains from a fossil meteorite have retained cosmogenic noble gases during 480 Ma residence on Earth and therefore were not (significantly) diagenetically altered. The calculated exposure ages are unusually young for ordinary chondrites. Analyses of chromite grains from further meteorites are expected to show whether these low ages are typical for fossil meteorites from this site.

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References: [1] Schmitz B. et al. (2001) EPSL 194, 1-15. [2] Baur H. (1999) EOS Trans. AGU 46, F1118. [3] Leya I. et al. (2001) M&PS 35, 259-286. [4] Wieler R. & Graf T. (2002) in: Accretion of extraterrestrial matter throughout Earth's history (eds. B. Peucker-Ehrenbrink & B. Schmitz), Kluwer, 221-240. [5] Gladman B. J. et al. (1997) Science 277, 197-201. [6] Zappalà V. et al. (1998) Icarus 134, 176-179.

Grain	²¹ Ne/ ²⁰ Ne (10 ⁻³)	% err	³ He	% err	²¹ Ne	% err	T ₃	% err	T ₂₁	% err
C2.1	5.68	115	24	10	0.6	235	0.19	10	0.13	235
C2.3	16.6	22	31	12	1.8	19	0.25	12	0.39	19
NC2.4	18.6	9	37	6	1.7	10	0.31	6	0.37	10
NC2.6	13.6	9	35	16	1.9	19	0.29	16	0.42	19
NC2.7	12.7	16	29	14	1.4	24	0.24	14	0.31	24
NC2.9	18.2	26	34	14	1.5	17	0.28	14	0.33	17
Av-							0.26	16	0.33	32
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Table 1: Measured ²¹Ne/²⁰Ne-ratios, cosmogenic noble gases and ³He and ²¹Ne cosmic-ray exposure ages in six relict chromite grains from fossil meteorite Golvsten 001 measured with a high-sensitivity compressor ion-source noble gas mass spectrometer. Gas concentration are given in 10⁻¹⁰ cm³ STP / g, exposure ages in Myr. All uncertainties are 1 ☐. Uncertainties of exposure ages include only analytical errors.

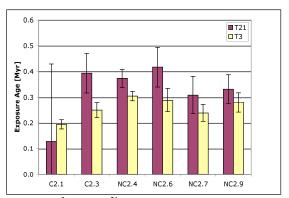


Figure 1: ³He and ²¹Ne exposure ages in Myr. All uncertainties are 1 . Uncertainties of exposure ages include only analytical errors.